In the 1970 Baneberry Test, a 10-kiloton device was detonated approximately 900 feet underground. Despite a careful geological analysis of the test site and appropriate backfilling of the test shaft, undiscovered geological features allowed the blast to breach the surface. The resulting radioactive dust plume is shown here. (Photo: Los Alamos)

NUCLEAR TEST READINESS

What is needed? Why?

In a national emergency, could the United States safely test a nuclear weapon tomorrow? Is Nevada still the obvious place to conduct a nuclear test? John C. Hopkins, former head of the Los Alamos Nuclear Test division, contemplates the challenges of reviving—and possibly relocating—America's nuclear testing program.

I am one of the dwindling number of people left who participated in U.S. nuclear weapons tests. I participated in five tests in the Pacific in 1962 and some 170 tests in Nevada in the 1960s through the 1980s. I witnessed another 35 or so nuclear tests.

Because I know something about the skills, equipment, facilities, and infrastructure necessary to field a full-scale nuclear test, I have grown increasingly concerned at the steady degradation of U.S. nuclear test readiness—that is, the capability of the United States to test its nuclear weapons should the need to do so arise.

In fact, my review of assessments made by the Department of Energy (DOE) of U.S. nuclear test readiness leads me to question whether the DOE has, after almost 25 years of being out of the testing business, any realistic appreciation for what nuclear testing involves or how to stay prepared to do it again within 24–36 months, as legally required by Presidential Decision Directive 15 (1993).

Starting up or starting over?

Nuclear testing as we did it at the Nevada Test Site (NTS, now called the Nevada National Security Site, or NNSS) was a profoundly large and complex endeavor. The 1,375-square-mile site sits about 65 miles northwest of Las Vegas and was used from 1951–1992 for 928 atmospheric and underground nuclear tests. Back then, the U.S. nuclear enterprise was not just a program; it was a nationwide industry that required more than 100,000 highly trained, experienced people. During the Cold War—peak testing years—we averaged about one test a week, and NTS employed more than 7,000 people onsite. (See "Nevada National Security Site Turns 65," page 2.)

According to the National Nuclear Security Administration (NNSA)—the organization within the DOE obligated to maintain U.S. test readiness—much, if not most, of the equipment and technology required for nuclear testing in the past has not been adequately maintained, is obsolete, or has been sold or salvaged. More importantly, the knowledge needed to conduct a nuclear test, which comes only from testing experience, is all but gone too. Currently, no federal funding directly supports maintaining test readiness (although the government does fund subcritical tests; see “Do Subcritical Experiments Help?” page 16).

In sum, there is essentially no test readiness. The whole testing process—whether to conduct one test or many—would in essence have to be *reinvented*, not simply resumed.

If the United States decided tomorrow that it wanted to test a weapon in the nuclear triad (see “Why the Nuclear Triad,” page 17), the path to actually do so (safely) would be long and complicated, and it would look something like this:

Where could we conduct a nuclear test?

This answer largely depends on how soon the president, who orders the test, wants the test to happen.

> **At first look, the NNSS is the obvious place to resume testing. But in reality, this is far from certain.**

In an emergency—such as the need to evaluate the safety, security, and performance of an existing but questionable nuclear weapon design—I assume that we would test underground and not abrogate the 1963 Limited Test Ban Treaty that bans tests in the atmosphere, oceans, and outer space. I also assume we would adhere to the 1974 Threshold Test Ban Treaty, which limits tests to a maximum yield of 150 kilotons of TNT. (Nuclear yield is the amount of energy released, expressed as a TNT equivalent. A kiloton is 1,000 tons, so the treaty limits yield equivalents to no more than 150,000 tons of TNT.)

At first look, the NNSS is the obvious place to resume testing. But in reality, this is far from certain. More than 800 of the nuclear tests there were conducted underground in deep shafts (or sometimes tunnels). More than a dozen shafts still exist that *might* be serviceable.

However, since the last underground test in 1992, nearby Las Vegas has exploded in population. In 2015, the city had 630,000 residents—360,000 more residents than in 1990. (In 1951, the year testing began, the population of Las Vegas was about 25,000.) In 2015, the greater Las Vegas metropolitan area had a population of more than 2.1 million—1.4 million more people than in 1990.

> **In 2015, the greater Las Vegas metropolitan area had a population of more than 2.1 million, 1.4 million more people than in 1990.**

More people equals more buildings. Today, Las Vegas has more than 50 buildings over 328 feet tall (25 stories high), including the 1,150-foot Stratosphere Tower, the tallest observation tower in the United States.

What is the maximum yield that could be fired at the test site without causing seismic damage to Las Vegas infrastructure and its surrounding communities? Will recent construction be resistant to seismic energy following a 150-kiloton blast? Will future maximum test yields have to decrease as the local population increases?

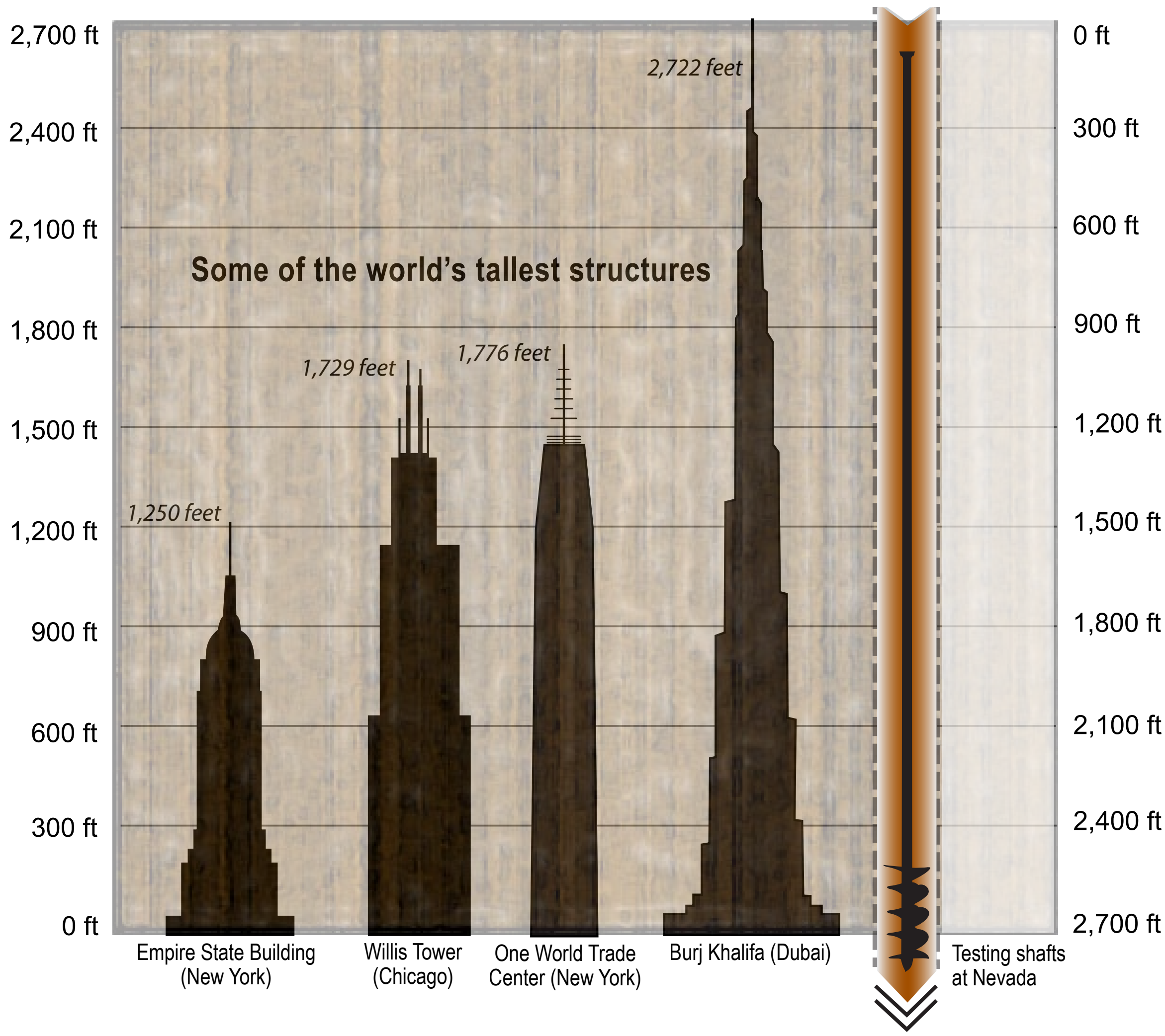
How big of a test could be conducted in Nevada?

The answer to this critical question lies in accurately predicting the seismic effects of a nuclear test's yield at NNSS on Las Vegas and the surrounding communities.

Detailed geologic and safety analyses of the current Las Vegas area would be required to develop a prudent estimate of the upper limit of the yield. Ultimately, scientific judgment would play a key role in this estimate, but that judgment would rely on recommendations coming from relatively young scientists and engineers who have no experience in nuclear testing.

Previously, the Atomic Energy Commission (the predecessor to today's DOE) hired an engineering contractor to analyze the structural integrity of buildings in Las Vegas and their vulnerability to ground motion due to nuclear explosions. Test readiness means that buildings—especially skyscrapers—

Left: A mushroom cloud is visible from downtown Las Vegas. This scene was typical from 1951 to 1962 as the government conducted 100 atmospheric tests at the NTS. Right: Downtown Las Vegas in 2010. *(Photos: DOE, Open Source)*



During the period of underground testing at the NTS, 13 shots were fired at a depth of 3,000 feet or more; six of those were fired at least 4,000 feet below the surface.

and the greater metropolitan infrastructure would have to be carefully evaluated. Reconstituting this program would require a major effort.

Throughout the testing period, Las Vegas construction workers were notified when an upcoming shot might cause significant ground motion. The reasoning was that such shaking could be unsafe for workers in exposed locations, particularly at high-rise construction sites. Mines in the region were also notified of ground motion that could conceivably cause damage and injury. A new plan to communicate a testing schedule to the civilian workforce would have to be developed.

How can seismic effects be mitigated?

"Decoupling" an explosion can mitigate seismic energy. Decoupling involves testing the nuclear device in an underground cavity large enough to absorb—and thus reduce—the force of the blast. Higher yield explosions require larger cavities. Larger cavities require significantly more time, effort, and cost to excavate. The National Academy of Sciences estimates that, depending on geology, a cavity 121 feet in radius requiring the removal of nearly 7.5 million cubic feet of material, would be needed to decouple a 3-kiloton test.

How can a nuclear test be contained?

The risk of venting—the leaking of radioactive materials from the ground into the atmosphere—must be minimized. An underground test was designed to prevent venting. In the past, preventing venting was a major challenge for the geologists, engineers, and construction crews at the test site.

Previously, we selected a location and designed the emplacement shaft to contain a yield that was usually about 10 percent larger than the expected yield. Successful containment depended on studying the geology at each test

Gas-blocked cables are shown here laid out in an s-shape prior to an underground nuclear test. The cables were lowered down-hole along with a giant steel rack that contained the test device and multiple diagnostic sensors used to gather data. The cables relayed the data up to trailers (shown here in the foreground and parked at a safe distance from the detonation) containing the data recording equipment. In the background is a 10-story tower assembled around the giant rack and directly over the test hole. The tower was disassembled and removed in sections after lowering the rack but before the detonation. The tower was then reassembled over the next test hole. *(Photo: DOE)*

location—no two test locations had the same geology—to see if the shaft could contain the test after successfully stemming (backfilling) the shaft.

Stemming was both a science and an art, and few experts with stemming experience can still be found.

To be effective, stemming required an experienced expert to layer a special brew of adhesive epoxies (which are no longer available) and various types and sizes of gravel. This mixture would then be packed around specially designed gas-blocked cables that were used to transmit command-signals down-hole and send scientific data up to the surface. (The cables were gas-blocked to prevent any venting up through the cables, and I doubt whether these special cables are still available. If not, they would have to be redesigned, tested, and manufactured anew.)

Each test's stemming was unique, varying with the test's predicted maximum yield and a thorough study of the geology surrounding the shaft. Stemming was both a science and an art, and few experts with stemming experience can still be found.

All of the geophysical tools that were, over many years, designed, built, tested, calibrated, and fielded at the NTS specifically to collect samples and characterize the geology no longer exist. The designers and operators are long gone, too. The Laboratory analysts who had the skills and experience to evaluate the samples for grain density and for compressive and sheer strength are likewise long gone.

Today, the kind of detailed geologic and safety analyses and yield predictions needed to successfully contain a nuclear test would depend upon people who have no nuclear testing experience.

Amchitka is part of the Alaska Maritime National Wildlife Refuge, and going back there to test would be concerning to environmentalists and Native Alaskans.

Even with stemming, the risk of venting could never be reduced to zero. Dangerous surprises (for example, unknown cracks, caves, or moisture) might be lurking right next to the area of geologic sampling. One dramatic failure was the huge venting from the 1970 Baneberry shot, which was caused by undiscovered geological problems at the test site.

To be prudent, we always assumed that massive venting might occur. So, we were in touch with all of the potential downwind residents and had helicopters ready and evacuation plans for every rancher out mending fences and every sheepherder tending to his flock—anyone who might be at risk the day of a test.

What would it take to plan and implement emergency evacuations close to the NNSS today?

What about sticking to lower-yield tests?

The NTS was originally chosen for nuclear testing largely because of its remote location at that time. Once testing went underground, we soon discovered that, fortuitously, the geology is nearly ideal for reducing venting and seismic impact—thus limiting negative impacts to the environment caused by higher-yield (more than 10 kiloton) tests.

> **How to revive these critical, complex, and costly skills for a future nuclear test must be addressed.**

The water table at the NTS is deep: 1,300 feet at Yucca Flats, where low-yield shots were traditionally fired, and 2,000 feet at Pahute Mesa, which was used mostly for high-yield shots. The overlying layers of weak, porous tuff and alluvium provide dry pore space to trap radioactive gases. The site's easily crushable porous tuff would also significantly absorb the seismic waves of our higher-yield tests.

But surprisingly, and perhaps counterintuitively, low-yield nuclear tests are harder to contain at the site. In part, this is because the crushable tuff doesn't crush as well from lower-yield tests, meaning that the risks of venting increase. So, risks to the environment actually loom larger. Successfully stemming a lower-yield test is actually more difficult.

These risks can be addressed by burying a low-yield test as if it were higher-yield test, but this approach requires the commensurate level of time, effort, and expense of conducting a higher-yield test. Therefore, the better approach is to design an effective containment plan at the nominal depth required for the lower yield, assuming that the expertise necessary to do this is available.

Clearly, the assumption that focusing on lower-yield tests gets us any closer to nuclear test readiness needs a closer look.

If not in Nevada, then where?

If challenges preclude using NNSS, an alternative testing site would be required. Amchitka Island in the Alaskan Aleutians Islands would probably be the next best candidate site. Three tests were fired there: Longshot (1965) and Milrow (1969) by Los Alamos and Cannikan (1971) by Lawrence Livermore.

However, not much infrastructure is left on the island other than an airstrip and perhaps two holes that were, at one time, meant for future nuclear tests. All the buildings are gone. The lack of infrastructure, great distance, and remote location make Amchitka vastly more expensive and inconvenient than working in Nevada. The island also has a wretched climate with dense fog and rain. In addition, Amchitka is now part of the Alaska Maritime National Wildlife Refuge, and going back there to test would certainly be concerning to environmentalists and Native Alaskans.

Do other locations exist? Studies of alternative sites have been made in the past, but like at Amchitka, political, cultural, and natural environments have changed since those studies were undertaken. New, costly, and time-consuming assessments would need to be done. Should the nation be actively searching?

Critical skills and assets

As might be imagined, many unique and critical assets—facilities, materials, and equipment, much of which is not commercially available—must be available to successfully execute an underground nuclear test.

Amchitka has been part of the United States since the Alaska Purchase of 1867. During World War II, the volcanic island was home to a U.S. airfield; during the Cold War, Amchitka was the site for three underground nuclear tests. The last test, the 5-megaton Cannikin Test (1971), is the largest underground test ever conducted by the United States.

Tests fired in shafts, for example, had the nuclear device and the experimental equipment installed inside a tall, steel structure called a rack, which was lowered down-hole. The racks, which were designed and fabricated specifically for each shot, could be almost 10 feet in diameter and more than 100 feet tall. The assembly of all the experimental equipment required that the rack be surrounded by a tower, built of prefabricated units, that was large enough for the scientific and engineering staff to work onsite at all levels of the rack.

Seemingly mundane perhaps, but vital, are requirements for housekeeping and security.

The Los Alamos racks were fabricated at Los Alamos and shipped to Nevada to install the scientific equipment. The nuclear test device was installed as the last step before the rack was carefully lowered down-hole on cable harnesses, which were also fabricated at Los Alamos. Livermore's racks were fabricated by a contractor in Las Vegas and were lowered using drill pipe, a completely different technique. Pros and cons exist for each option.

How to revive these critical, complex, and costly skills for a future nuclear test must be addressed.

The stakeholders

After two decades without testing, who would be the current stakeholders, and what would their roles and responsibilities be? What are the challenges to negotiating new and complex chains of command and responsibility?

The White House, DOE, NNSA, Department of Defense, and the state of Nevada would be among the key stakeholders, along with more than a dozen other government organizations such as the Defense Nuclear Facilities Safety Board, the Defense Threat Reduction Agency, the Environmental Protection Agency, the U.S. Public Health Service, the National Oceanic and Atmospheric Administration, the State Department, and Congress.

Because the United Kingdom's nuclear strategy is closely allied to ours, I presume the U.K. would participate where its national security interests are involved. Imagine the difficulties of getting all these gears to smoothly mesh together.

Subsidence craters—depressions on the surface that occur when the roof of the blast cavity collapses into the void left by the explosion—still mark the surface of Yucca Flat, where many underground nuclear tests were conducted at the NTS. The size of subsidence craters depends on the yield of the device, the depth of the test, and the geological characteristics of the surrounding soil. (Photo: DOE)

Although Los Alamos, Livermore, and Sandia national laboratories would supply much—if not most—of the technical staff, the majority of the testing personnel would come from a wide range of outside organizations. Contractors for the NNSA would do almost all construction, related logistics, and other support work.

These contracts might include providing test diagnostic support (once supplied by EG&G, which no longer exists) and the architect/engineering support (once supplied by Holmes & Narver Inc., which is still in business).

The now-defunct Reynolds Electrical & Engineering Company provided the heavy construction services, including operating cranes and drilling shafts, some of which were more than 4,000 feet deep. The technology and expertise to drill new, large-diameter, deep, and straight testing shafts would almost certainly have to be recreated. Significant economical and technological challenges would arise if the pre-moratorium-drilled shafts need to be cleaned of debris or pumped dry of water.

Seemingly mundane perhaps, but vital, are requirements for housekeeping and security. Currently, a few of these requirements are being met at the site (to accommodate staff conducting subcritical experiments, for example), but these requirements would have to be expanded to accommodate a much larger operation. Other services—for example, recreational programs and facilities—would have to be completely reinvented.

The labs

I would strongly urge the three nuclear weapons labs to form one unified test program, with each lab having well-defined responsibilities and clear accountability. (Previously, each lab had its own testing programs.)

I would recommend pulling together a steering committee of the labs' key staff, including weapons designers and engineers, diagnostic scientists (such as physicists and radiochemists), geologists, engineers (civil, mechanical, and electrical), and logistics and travel personnel. (A scaled-down version of this type of organization probably exists today as a result of the subcritical tests currently conducted in Nevada but probably lacks all the expertise needed to execute a full-scale nuclear test.)

> **The time delay following the decision to resume testing would, in my opinion, be dangerously long.**

I would suggest that the labs' test program leaders put a high priority on selecting an archivist. Perhaps not obvious, the rationale for the archivist is this: In developing the testing organization and structure, there will be many questions about what, how, and why things were done in the past. Laboratory archivists could make answering those questions much easier, assuming that the old testing files are stored somewhere in the labs and can be found.

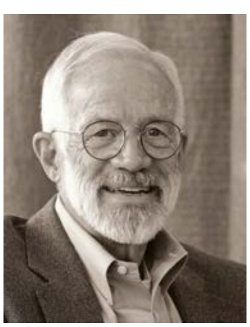
Making nuclear test readiness a priority

With every day that passes, the United States grows more out of practice and out of resources—including the most important resource: people with experience—that are critical to nuclear testing. The testing process, whether for one test or for many, would in many respects have to be *reinvented*, not simply restarted, which would take longer than 36 months. Past practices will help identify *what* to do but not necessarily *how* to do it—primarily because science, technology, politics, and culture have changed so dramatically since 1992.

A resumption of nuclear testing would involve a large, expensive, and complex program. Because the United States has little left from its previous test program, and essentially no test-readiness program, the time delay following the decision to resume testing—because of a loss of confidence in the stockpile or to a geopolitical crisis—would, in my opinion, be dangerously long.

Let's not wait to find out how long.

~John C. Hopkins



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I alone take responsibility for the opinions expressed in this article.

Do Subcritical Experiments Help?

Although the United States halted full-scale nuclear weapons tests almost 25 years ago, the nation does conduct small-scale subcritical nuclear experiments using plutonium and high explosives.

These subcrits, as they're called, are underground experiments at NNSS that are typically conducted safely inside steel confinement vessels. Subcrits are intended to help scientists study—without a full-scale nuclear weapon test—what, for example, are the negative effects aging plutonium pits have on the performance (yield) of weapons in the U.S. nuclear stockpile. (Rocky Flats, where plutonium pits were manufactured, closed in 1989.)

In a typical subcritical experiment, a small shell of plutonium is imploded using high explosives, increasing the plutonium's density until...there isn't a nuclear explosion. And that's the point. Unlike a full-scale nuclear weapons test, a successful subcrit ends without a nuclear bang—not even a whimper. The pit assembly doesn't have enough plutonium or high explosives to reach a critical mass.

A critical mass is the minimum amount of nuclear material (typically plutonium or uranium) needed to initiate the self-sustaining chain reaction that releases huge amounts of nuclear energy—aka a nuclear explosion. In a subcrit, the mass of plutonium used to make the pit remains subcritical. A self-sustaining nuclear chain reaction isn't possible; there is no nuclear yield, no nuclear explosion. The experiment is in line with the nuclear testing moratorium while allowing scientists to study, for example, how aging plutonium pits perform right up to just before going critically nuclear.

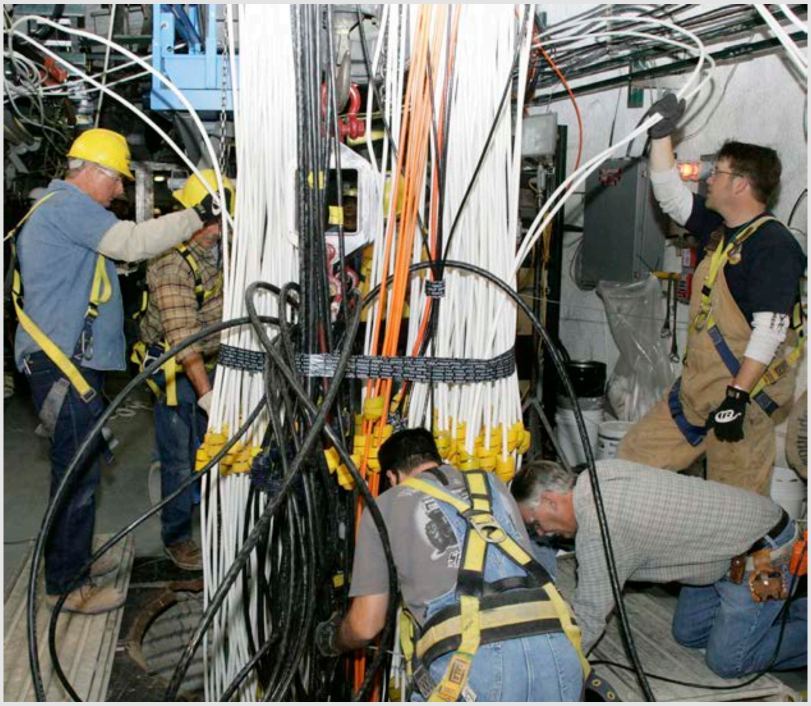
So, do subcritical experiments help maintain U.S. test readiness?

Yes, in the sense that all subcrits are relevant to maintaining test readiness because they exercise *some* of the aspects and skill sets used in full-scale testing, such as firing shots, employing specialized diagnostic equipment, and gathering data.

However, subcrits are small scale. A full-scale nuclear test, which reveals how well the entire device works from start to finish, is quantitatively and qualitatively different in many key ways. For example, safely containing a full-scale test requires the skills and equipment for carefully studying and geologically characterizing a test site, drilling an appropriately deep shaft, emplacing the test device and all of its diagnostic-related equipment deep underground, and then properly containing (stemming) the shaft so the massive detonation doesn't breach the surface.

These—and other critical skills—are not currently exercised by doing subcritical experiments.

In short, though valuable, subcrits don't address all of the issues required to maintain test readiness within a 24- to 36-month timeframe.



The Nevada National Security Site is the only place where subcritical experiments using plutonium and high explosives can be conducted. The U1a laboratory at the site, constructed nearly 1,000 feet underground, is where these experiments are typically conducted. Here, workers prepare to conduct an experiment in the U1a laboratory. (Photo: Los Alamos)